

Behavioral Changes in Adult Rats Exposed to ELF Magnetic Fields

by

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ELF (extremely low frequency) electromagnetic fields and waves with intensities similar to and slightly larger than those which occur in nature have been shown to be associated with changes in reaction time (Friedman, Becker and Bachman, 1967; König, 1962; Reiter, 1964), and verbal behavior (König, 1962; Ludwig and Mecke, 1968) in human subjects.

Hamsters exposed to naturally occurring atmospherics show decrements in ambulatory activity (Ludwig and Mecke, 1968). Exposure to artificial fields (1 v/m) with carrier frequencies of 10-100 kHz and 20, 10 or 5 Hz impulses is associated with a similar decrease in ambulation. Mice exposed to a time-varying field of 1.75 Hz, and 5 Hz (40 v) also show a decrease in ambulatory activity (Altmann, 1969). According to Ludwig and Mecke (1968) the removal of either the E or H component of the applied field is followed by an increase in activity the next day.

In a series of unpublished experiments (Persinger, 1967), rats that had been exposed during a 368 day period to an ELF (0.5 Hz), 3-30 gauss rotating magnetic field (RMF), showed a marked, significant increase in intragroup aggressive behavior, after 140 days of exposure. In two other separate experiments, RMF-exposed adult rats, when removed from the field showed a significant increase in open field activity and errors during Y-maze acquisition. Although prenatal exposure to ELF-RMFs have shown to be associated with a variety of consequent behavioral changes (Persinger, 1969, 1971; Persinger and Foster, 1970; Persinger and Pear, 1971), it was decided to further explore the possible behavioral modifications in connection with adult "chronic" exposure to these fields. Since in the initial studies, changes in open field behavior were observed, it was decided to replicate this study using controls that would minimize possible experimenter bias.

METHOD

SUBJECTS. In three experiments (Experiments I, II and III), 16, 15, and 12 male naive rats, 30, 160, and 100 days of age, respectively, at the beginning of the experiments were used as subjects. The subjects were selected from Sprague-Dawley, Holtzman and Wistar strains in Experiments I-III respectively.

APPARATUS. Two rotating magnetic field (RMF) apparatus were used. Essentially, the RMFs were created by two horseshoe magnets rotating in opposite directions about their major axes at 30 rot/min (0.5 Hz). The magnets in apparatus A, a diagram of which has been published earlier (Persinger and Pear, 1971) were rotated by an electric motor that drove a pulley-shaft system to which the magnets were attached. In apparatus B, shown in Fig. 1, each magnet was turned by a separate variable speed transmission. In Experiments I-III, the major axes

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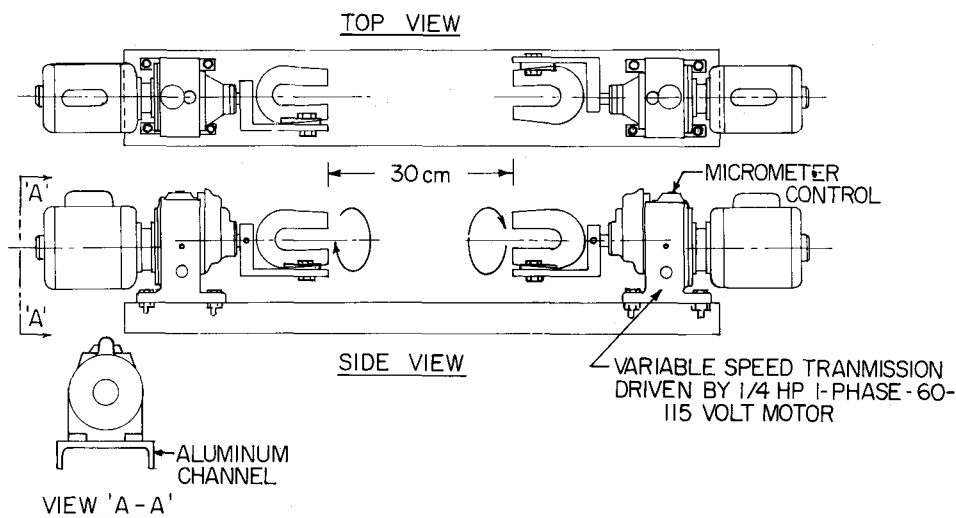


Fig. 1. RMF-apparatus B. Exposure area was between the two magnets.

of the magnets were aligned in a NW-SE direction in Menomonee Falls, Wisconsin; Madison, Wisconsin, and Knoxville, Tennessee, USA, respectively, and rotated in either a counter-clockwise (Experiments I-II) or clockwise (Experiment III) direction with respect to the NW direction. The intensity of the RMFs (as measured by a Rawson-Lush Gaussmeter) in the exposure cages in which the rats were housed, varied from 3-30 gauss (average about 10 gauss) with RMF-apparatus A to 3-50 gauss (average about 20 gauss) with apparatus B. More details concerning the characteristics of these fields are reported elsewhere (Persinger, 1969; Ossenkopp, Koltek and Persinger, 1971).

OPEN FIELD APPARATUS. For Experiments I and II, a 40 cm x 40 cm brown wooden plank divided into 16 squares was used as the open field. A 60 cm masonite wall prevented the rats from escaping from the open field. Illumination of the field was furnished by a 75-w incandescent light 100 cm above the field's surface. Since the open field was in the same room as the home cage, the background sound pressure level averaged 72 db.

For Experiment III, the wooden floor of a 120 cm x 120 cm open field covered with white oil cloth was divided into 16 squares. The 50 cm high walls were also covered with white oil cloth. Illumination was furnished by a 20-w fluorescent lamp 150 cm above the surface of the open field. Since the open field, in this experiment, was not in the same room as the RMF, the background sound pressure level, supplied by a white noise generator, averaged 72 db.

PROCEDURE. Animals of a given condition were housed in groups in one of two plastic cages (27 x 50 x 30 cm). The cages were covered with wire mesh tops and with cardboard on all four sides, so that light from each cage's lamp entered only through the top. One cage in each experiment was placed between the magnets of either RMF apparatus A (Experiment III) or apparatus B (Experiments I and II). Since the motor in apparatus A was secured to a plywood base and produced some vibration, the cage was placed on a platform 1.3 cm above and independent of the base. The other cage was placed in the control area 2 m from the nearest magnet. Although a Rawson-Lush Gaussmeter showed no deviation at this distance, a

compass (3 cm needle) registered a $1-3^{\circ}$ change in declination. The rats were exposed to the experimental (RMF and control) conditions in Experiments I-II, on 2 June 1966, 2 January 1967 and 13 June 1969.

Sanicel was used as absorbent material in the cages and was removed once every five days in order to minimize handling of subjects. During cleaning, the RMF-exposed rats were out of the field for 3-4 min. Illumination throughout the experiments was constant and was furnished by a 20-w fluorescent lamp 45 cm above each cage. Temperature averaged $25^{\circ} \pm 2^{\circ}\text{C}$, but did not vary by more than 0.5°C between the RMF and control cage. Background sound pressure level (as measured by a B and K precision sound level meter) average 67 ± 3 db in the exposure area of RMF-apparatus A (from the motor) and 65 ± 4 db in the control area. As a comparison, the background sound pressure level in the department's main colony room was 62 ± 2 db. Other physical variables were not recorded. Rats received Purina food and water ad libitum.

When the subjects had been exposed to the RMF and control conditions for 21 days (Experiments I and II) or 30 days (Experiment III), each rat was placed in a carrying cage and taken to the open field at the other side of the room (Experiments I and II) or in another room. The latter procedure took 30 sec. The rat was immediately placed upon one of the corner squares of the open field. The number of squares traversed in 30 sec (Experiment I and II) or 120 sec (Experiment III) was recorded. At the end of the test, the rat was tail marked (Experiments I and II) or ear-punched (Experiment III), and returned to the carrying cage. After the field had been sponged with 0.4% acetic acid (vinegar) the rat was taken to a temporary group housing for a given condition until the completion of the experiment. At that time all rats were returned to their respective cages.

Animals were again tested in the open field after 25 days of exposure (Experiments I and II, and 30 days of exposure (Experiment I, II and III). In Experiment III, the animals were again tested after 35, 40, 45, and 50 days of exposure. All rats in Experiment III were tested by a technician who did not know whether a rat had been exposed to the RMF or control conditions. Subjects were tested between 21:00 and 24:00 hr.

RESULTS

The average number of squares traversed in 30 sec (Experiment I and II) or 120 sec (Experiment III) for RMF-exposed and control rats in the three experiments is presented in Fig. 2. In Experiment I, the RMF-exposed rats, after 21, 25 and 30 days of RMF exposure, averaged 10.3 ± 2.4 (SD), 11.1 ± 3.8 and 12.3 ± 3.5 squares in 30 sec, while the controls averaged 11.5 ± 2.4 , 7.9 ± 3.2 , and 6.8 ± 9.1 squares. This difference was found by analysis of variance to be significant ($p < 0.05$; $F = 5.68$). A summary of the analysis is reported in Table 1. In Experiment II, the RMF-exposed averaged 11.0 ± 3.6 , 15.2 ± 4.9 , and 14.9 ± 3.3 squares in 30 sec, after 21, 25 and 30 days of exposure, while the control rats averaged 11.8 ± 5.3 , 6.1 ± 3.9 , and 5.0 ± 4.7 squares during this time. This difference was significant ($p < 0.01$; $F = 8.87$, Table 1). In Experiment III, where the rats were run for 120 sec in the open field per session, the RMF-exposed rats after 30, 35, 40, 45 and 50 days of exposure traversed 36.0 ± 8.9 , 32.5 ± 13.4 , 24.7 ± 13.3 , 19.2 ± 12.0 and 13.4 ± 8.6 squares while the controls averaged 29.1 ± 13.8 , 25.1 ± 15.0 , 11.6 ± 10.2 , 4.4 ± 6.3 , and 4.0 ± 5.4 squares on these days. This difference was found by analysis of variance to be significant only beyond the 0.10 level ($F = 4.27$). (In the analysis of the data from Experiment III, the squares traversed by each group in each of the 2 min in the open field were differentiated, so that a 2 (treatments) $\times$ 2 (min) $\times$ 5 (days) design was used.)

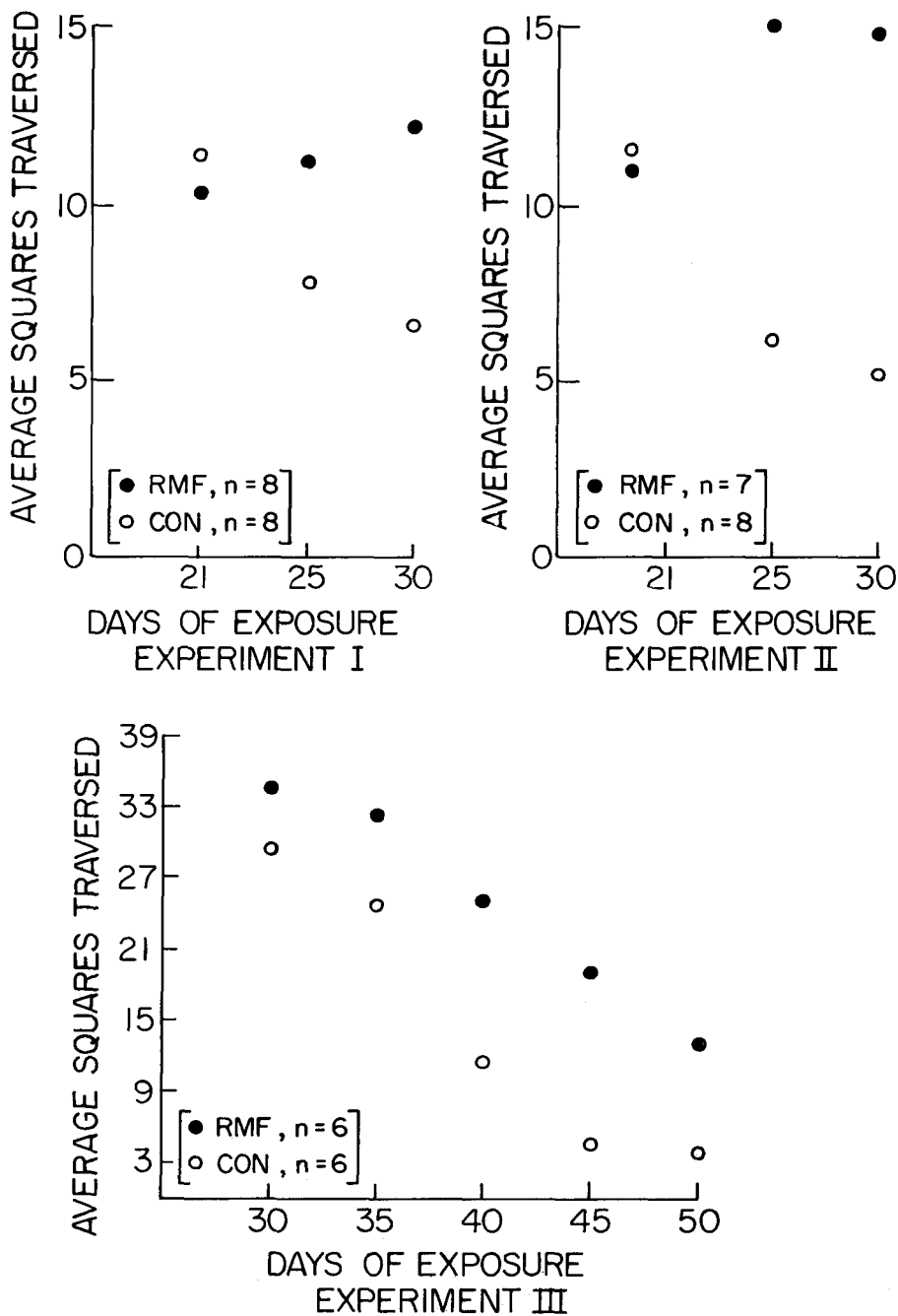


Fig. 2. Average squares traversed by RMF-exposed and control rats in Experiments I - III as a function of days of exposure.

TABLE 1. Analysis of variance for the mean number of squares traversed by RMF-exposed and control rats (df = degrees-of-freedom)

Source	MS	df	F
Experiment I			
Treatment (T)	74.9	1	5.67**
Error (a)	13.2	14	-
Days (D)	10.1	2	0.79
T x D	47.2	2	3.69
Error (b)	12.8	28	-
Experiment II			
Treatment (T)	40.7	1	8.87***
Error (a)	46.1	13	-
Days (D)	4.0	2	0.60
D x T	133.8	2	15.9
Error (b)	8.4	26	-
Experiment III			
Treatment (T)	730.2	1	4.27*
Error (a)	171.2	10	-
Days (D)	693.3	4	30.29***
D x T	34.9	4	1.53
Minutes (M)	410.7	1	17.94
M x T	14.5	1	0.63
M x D	22.7	4	0.99
M x T x D	56.2	4	2.46
Error (b)	22.9	91	-

*) $p < 0.10$.**) $p < 0.05$.***) $p < 0.01$.

DISCUSSION

The results of the three experiments have demonstrated that the removal of male rats which have been exposed to an ELF-rotating magnetic field (RMF) for 21-50 days is associated with significant increases in ambulatory behavior. The reliability of this effect is suggested since a similar increased activity in the RMF-exposed group, relative to the control group, was also observed in a different testing apparatus by another experimenter who did not know whether a rat was from the RMF or control condition. The greater relative decrease in activity

of the control groups in the three experiments, following the first day of testing, also implies the consistency of the effect.

The results are compatible with previously reported experiments using different apparatus, intensities and wave form. Altmann (1969) and Ludwig and Mecke (1968) found that ELF fields were associated with a decrease in activity. Removal of the applied fields might, therefore, be expected to produce a "compensatory" increase ("rebound") in activity. Ludwig and Mecke (1968) do indicate that removal of the ELF field used in their study was followed by an increase in activity, although it occurred on the following day.

Such an increase of ambulatory activity following removal from the ELF-RMF could account for the increased errors (Persinger, 1967) displayed by the RMF-exposed animals during Y-maze acquisition, as noted earlier. "Scampering" or increased ambulator behavior as the animal approached the maze arms might interfere with alley discrimination. Persinger (1967) indeed reported that the RMF-exposed rats left the start box and ran down the alley "faster" than the control animals. This behavior could be interpreted as being associated with the RMF-exposed rats' relatively "less" habituation to testing situations. Thus, while the control rats were displaying less activity in the open field and fewer errors in the maze over test days, the RMF-exposed rats continued to exhibit behaviors associated with initial exposures to the test situation. In this context, it could be argued that the RMF was interfering with the physico-chemical processes associated with what has been termed "memory". Possible physiological correlates of RMF-exposure have been noted in another paper (Persinger, Glavin and Ossenkopp, 1972).

Despite the consistency of the open field results, considerable within group variability was observed since such tests are influenced by a multitude of uncontrolled environmental variables. It is strongly suggested by the experimenters that further research concerned with the effects of ELF magnetic fields (as well as other environmental variables), upon behavior incorporate the use of more precise operant techniques. These techniques utilize the basic reinforcement schedules (Ferster and Skinner, 1957) that control behavior. Operant techniques afford greater stimulus control, and minimize participation of the experimenter and experimenter error (Sidman, 1960). In addition, operant procedures have been shown to differentiate the behavioral effects of prenatal exposure to ELF-magnetic fields (Persinger and Foster, 1970; Persinger and Pear, 1971), which were not shown in other testing situations.

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REFERENCES

- ALTMANN, G. (1969) : Die physiologische Wirkung elektrischer Felder auf Organismen. Arch. Meteor. Geoph. Bioklim. B, 17 : 269-290.
- FERSTER, C.B. and SKINNER, B.F. (1957): Schedules of Reinforcement. Appleton-Century-Crofts, N. Y.
- FRIEDMAN, H., BECKER, R.O. and BACHMAN, C.H. (1967): Effect of magnetic fields on reaction time performance. Nature (Lond.), 213 : 949-956.
- KÖNIG, H. L. (1962) : Über den Einfluss besonders niederfrequenter elektrischer Vorgänge in der Atmosphäre auf die Umwelt. Z. angew. Bader- u. Klimaheilk., 9 : 481-501.
- LUDWIG, W. and MECKE, R. (1968): Wirkung künstlicher Atmosphäres auf Säuger. Arch. Meteor. Geoph. Bioklim. B, 16 : 251-261.
- OSSENKOPP, K.P., KOLTEK, T. and PERSINGER, M.A. (1972): Prenatal exposure to an ELF-low intensity rotating magnetic field and increases in thyroid and testicle weight in rats. Develop. Psychobiol. (in press).
- PERSINGER, M.A. (1971): Prenatal exposure to an ELF Rotating Magnetic field, ambulatory behavior and lunar distance at birth: A Correlation. Psychol. Rep., 28 : 435-438.
- PERSINGER, M.A., GLAVIN, G.B. and OSSENKOPP, K.P. (1972): Physiological changes in adult rats exposed to an ELF rotating magnetic field. Int. J. Biometeor., 16 : 163-172.
- PERSINGER, M.A. and PEAR, J.J. (1972): Prenatal exposure to an ELF-rotating magnetic field and subsequent increase in conditioned suppression. Develop. Psychobiol.,
- PERSINGER, M.A. and FOSTER, IV, W.S. (1970): ELF rotating magnetic fields: prenatal exposure and adult behavior. Arch. Meteor. Geoph. Bioklim. B, 18 : 363-369.
- PERSINGER, M.A. (1969): Open-field behavior in rats exposed prenatally to a low intensity - low frequency, rotating magnetic field. Develop. Psychobiol., 2 : 168-171.
- PERSINGER, M.A. (1967): The effects of pulsating magnetic fields upon the behavior and gross physiological changes of the albino rat. Unpublished Undergrad. Thesis. University of Wisconsin, Madison, Wisc., USA. Copyright Dec. 1967, Reg. // A976151.
- REITER, R. (1964) : Atmospheric Electricity and Natural Radioactive. In: Medical Climatology. S. N. Licht (ed.), Waverley Press, N. Y.
- SIDMAN, M. (1960) : Tactics of Scientific Research. Basic Books, N. Y.

ABSTRACT. - In two experiments, male rats that had been exposed to an ELF (0.5 Hz), 3-50 gauss rotating magnetic field (RMF) for 21-30 days, displayed significantly ($p < 0.05$) greater ambulatory behavior (activity) than the control group in an open field test, when removed from the RMF. In a third experiment rats were exposed to a different RMF apparatus (3-30 gauss), and tested in a different open field for longer duration. Again the RMF-exposed group displayed greater activity ($p < 0.10$) than the control group.

ZUSAMMENFASSUNG. - In zwei Untersuchungen zeigten männliche Ratten, die einem ELF (0,5 Hz) 3-50 Gauss rotierenden magnetischen Feld (RMF) für 21-30 Tage ausgesetzt wurden, in einem Open-Field Test signifikant ($p < 0,05$) mehr Bewegungsaktivität als die Kontrollgruppe, nachdem sie von dem RMF entfernt wurden. In einer dritten Untersuchung wurden Ratten in einem anderen RMF Gerät gehalten und in einem anderen Open-Field für längere Zeit getestet. Wieder zeigte die Gruppe, die dem RMF ausgesetzt war, mehr Bewegungsaktivität ($p < 0,10$) als die Kontrollgruppe.

RESUME. - Lors de deux essais, on a placé des rats mâles dans un champ magnétique tournant (CMT) de 3 à 50 gauss et des très basse fréquence (FTB) (0,5 Hz). Après 21 à 30 jours de ce traitement, on les a remis dans des conditions normales. Leur activité (marche) était plus élevée que celle d'un groupe de contrôle et cela de façon significative ($p < 0,05$). Dans un troisième essai, d'autres rats furent placés dans un autre appareil (3 à 30 gauss) et examinés ensuite dans un autre champ ouvert sur une plus longue période. Le groupe traité a déployé dans ce cas également une plus grande activité qu'un groupe de contrôle ($p < 0,10$).